HUYGENS AND NETLANDER: A SYSTEM OVERVIEW

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ABSTRACT

HUYGENS and NETLANDER are two major European missions dedicated to the comprehension of neighbouring planets. Both are entry probes that are finally destinated to land on outer worlds. However, these 2 probes for which the Entry and descent system were leaded by ALCATEL SPACE, presents different designs, related to the mission requirements and to the planet specificities. A comparison of the major element design and system trade-offs, performed for both probes are presented here, in order to compare the designs.

HUYGENS is an ESA mission, for which ALCATEL SPACE is the industrial prime contractor EADS for the entry analysis and by MBA-Vorticity for the Descent phase supports the system design.
NETLANDER was a CNES mission, for which ALCATEL SPACE was the prime contractor for the EDLS. CEA for the entry analyses, and by BABAKIN for the Descent and Landing System supports the system design.

ARD: Atmospheric Re-entry Demonstrator
CDF: Computed Fluid Dynamics
CNES: Centre National d'Etudes Spatiales
EDLS: Entry, Descent and Landing System
EMCD: European Mars Climate Database
FPA: Flight Path Angle
MBA: Martin Baker Aircraft
MOLA: Mars Orbiter Laser Altimeter
TPS: Thermal Protection System
TTG: Time To Go

1. Introduction

The understanding of the behaviour of neighbouring planets is a key issue for a better understanding of the Earth system. Two bodies in the solar system are particularly useful for exploration:

- Mars, a telluric planet with a thin atmosphere on which everyday new discoveries of geological features similar to Earth are done
- Titan, a Saturn satellite that is the only non-giant body after Mars that is surrounded by an atmosphere

1.1 Titan

Discovered by Christiaan HUYGENS in 1655, Titan was one of the objectives of the Voyager 1 mission. The Titan atmosphere is primarily composed of Nitrogen, as on Earth, and then composed of Argon and Methane. The major result of Voyager1 mission for Titan was the discovery of complex organic compounds and water in the atmosphere. These organic compounds are supposed to be issued through Methane photo-dissociation by sunlight. This atmosphere is unique in the solar system, as it could be a frozen replica of the Earth pre-biotic atmosphere.

After this discovery, a combined mission of ESA and NASA was built to reach Saturn, with the objective of in situ measurements in Titan's atmosphere. The ESA probe, called HUYGENS and thus referring to Titan's discoverer, will perform its mission early 2005. The probe is carried to Titan by the NASA CASSINI Orbiter, named after Giovanni CASSINI who discovered the division of the Saturn ring system. CASSINI will study the full Saturn system.

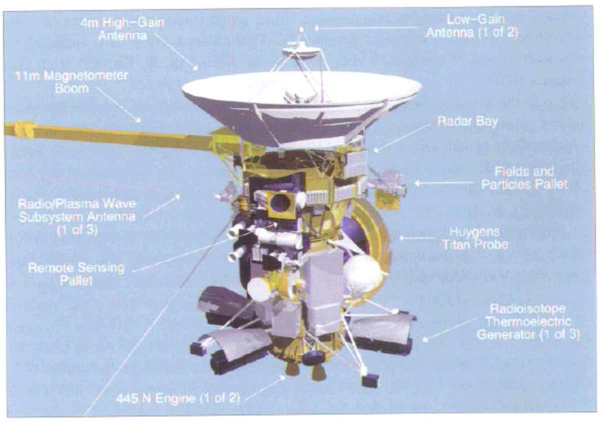

Fig 1 : The CASSINI-HUYGENS spacecraft [1]

1.2 Mars

Even if Venus is commonly referred to as the Earth's sister planet, Mars more resembles Earth by its morphology. Its evolution, with a thin atmosphere and clearly separated seasons, led to geological and atmospheric behaviour that can be compared to Earth. The potential presence of water in a Martian pergelisol is an other characteristic, which renders Mars more like Earth.

For more than 10 years, Mars is subject to numerous missions to enhance our comprehension on the planet's dynamics and history. In the Mars characteristics that can be addressed for planet comparison, two are important:

- What is the Mars internal structure?
- What are the processes involved in the evolution of the Mars atmosphere?

In order to answer these two questions, it is mandatory to perform multi-site experiments with identical instruments for synchronised measurements. This demands to create a station network onto the Martian surface. This is the specific aim of the NETLANDER mission [2].

2. Mission objectives and specifications

2.1 HUYGENS

Derived from the aim of the mission, the scientific objectives are [1]:

- Determination of the atmosphere composition
- Study of the aerosol and cloud physics
- Measurement of the wind and global temperature

As the mission objective is the study of the atmosphere, from relatively large altitude on, a descent system has to be implemented to cope with this requirement. The altitude on which the instruments must be able to start their measurements have to be maximised. An other constraints for the descent device is the duration of this phase in order to be compatible with both energy available on board and with the visibility with CASSINI which relays the measurement data between HUYGENS and Earth. This descent was requested to be between 2h and 2.5h, before landing. The landing capability was not a requirement for the HUYGENS probe. A 3-minute survivability at Titan's surface was a design aim. One of the instruments, DISR, is an imager in several wavelengths. In order to cover the entire panorama, a spin has to be imposed to the probe, with a magnitude range compatible with the instrument imaging process. A spin requirement between 1 rpm and 15 rpm has been defined. The velocity at the atmosphere entry point (1270km altitude) is defined by the trajectory definition of the CASSINI orbiter and thus separation conditions. This velocity is of 6040 m/s for HUYGENS.

2.2 NETLANDER

The NETLANDER mission includes two scientific packages to treat both geophysical and atmospheric topics:

- Geophysics: The package mainly includes a seismometer, a magnetometer and other geodesy experiments [2].

At least three stations are necessary for the scientific purpose, but four gives the sufficient degree of reliability for the mission and an improvement in the measurement accuracy. In addition, implementation of one station at the antipode from the network will provide an estimation of the Mars core size via the seismometer-synchronised measurements.

- Atmosphere: An identical package on the four stations with synchronised measurements will largely improve the knowledge on the atmosphere dynamics. The package includes measurements of temperature, pressure, optical depth and wind characteristics [2].

The mission requirements define that all stations have to be operational <u>together</u> on Mars, on different landing sites spread all over Mars surface. This dispersion on Mars induces for the probe to be compliant with a wide range of landing sites. The full longitude range has to be reachable, with a limitation in the latitude of [-30°;+35°], limited by the surface station energy budget which is powered via solar arrays. The landing altitudes have to be lower than 0km, MOLA reference, in order to limit the constraints on the probe (descent system sizing).

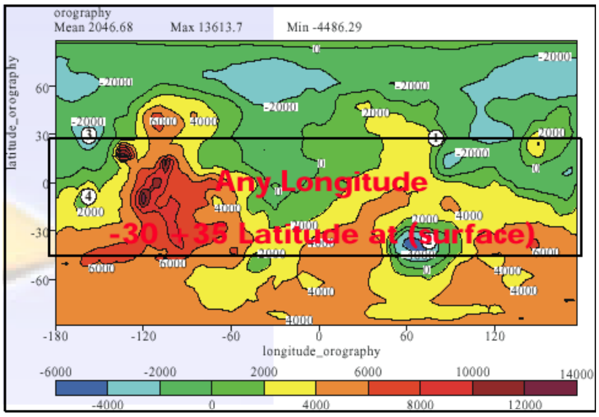

Fig 2: NETLANDER Landing range on Mars

Depending on the launch date from Earth and of the trajectory chosen to go to Mars, the arrival can happen in different Martian seasons, but should always be far from the dust storm seasons. Depending again on the launch date, the entry velocity will be between 5300m/s and 5900 m/s.

3. Atmospheric entry vehicle constraints and concept

The driving constraint of an entry vehicle can be expressed as follows: the mission has to be performed at a low velocity, 0m/s for a landing, and few 100m/s for descent, while the arrival from orbit of interplanetary trajectory is of several 1000-s of m/s. For both HUYGENS and NETLANDER, the ΔV is about 6000m/s. The concept considered to reach such enormous ΔV decreases, is to use the atmosphere as a decelerator. The "mission module" is then embedded in an aeroshell which shape is defined in order to allow an as large drag as possible to create an efficient deceleration, and then to reach the ground at a reasonable velocity. Blunt body aeroshells are chosen as they exhibit large drag capabilities during atmospheric entry. Sphere-cone shapes for the front shield are generally preferred for unmanned spacecrafts. However, the blunt body aeroshell shape is not enough efficient in subsonic flow. Parachute systems are then used to cross the transonic unstable flow and to reduce the velocity to a low level, below 30m/s, to allow for a safe landing. Such mission concepts were chosen for both HUYGENS and NETLANDER.

4. Atmosphere models

Before starting to perform the different trade-offs with regard to the probe design, the first important input required is to have an atmospheric model.

4.1 Titan atmosphere model

For the purpose of the HUYGENS project, several engineering models were developed in order to design the probe according to best expectations of the Titan atmosphere characteristics. A dedicated atmosphere engineering model was then developed in the late 80's by Lellouch and Hunten, [3]. This model presented the mean characteristics of the Titan atmosphere. Three models are possible, all in accordance with the available measurements, the recommended model, and the minimum and maximum models introducing atmospheric dispersions.

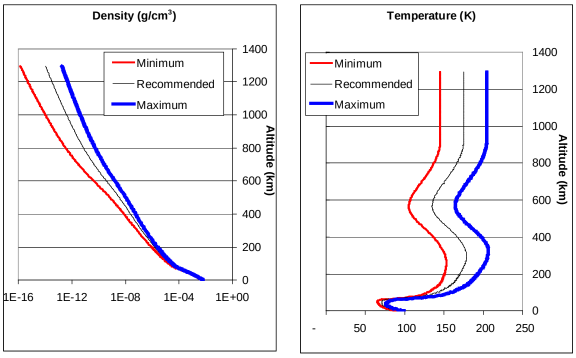

Fig 3: Titan atmosphere model

The following potential composition of the Titan atmosphere is included in this model:

Table 1: Titan atmosphere composition (LH)

Methane	Argon	Nitrogen
0.5% to 3.5%	0% to 20%	76% to 99%

This composition model is paramount for the heat flux evaluation.

4.2 Mars atmosphere model

Atmospheric data collected by both VIKING Lander and Orbiter missions, and by Mars Global Surveyor, have allowed producing general circulation models for Mars atmosphere. The European Mars Climate Database, EMCD [4], was used for the NETLANDER design. This database provides the characteristics of the atmosphere, i.e. density, temperature, pressure, wind velocity and direction, and some surface characteristics such as the albedo. This data is a function of the location, longitude and latitude, the altitude, the date in the Martian year, the local time, and of the dust model. Dust is an important parameter in the Martian atmosphere as its concentration can largely modify the overall density, where a dustier atmosphere leads to a lower density. In addition, the influence of dust appears even in hypersonic region of the entry phase as the upper level of dust can reach 70km, where the maximum level on Earth is of about 15km.

4.3 Atmospheres comparison

Fig 4 shows a comparison of atmosphere density between Titan, Mars and the Earth. The Titan atmosphere is very dense, with a level of 1.5 times the density of earth's atmosphere at surface level. This is the opposite for Mars where the ground density is less than 1% the Earth's density.

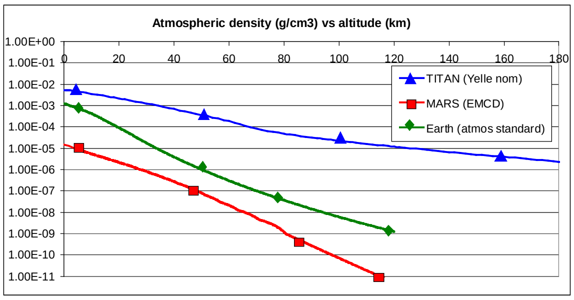

Fig 4: Atmosphere density comparison

Hence, for a similar entry velocity, the deceleration will be more efficient on Titan or Earth than on Mars. It will be seen later that the altitude for parachute phase is much higher on Titan than on Mars.

5. Probe Entry, Descent an Landing System trade-off

A Probe Entry, Descent and Landing System, EDLS, is the system that is in charge of a safe descent and landing of the surface station through the atmosphere (no landing on HUYGENS). If a probe module is mainly composed of an aeroshell and parachutes, the trade-off between the different devices is of primarily importance for the mission performances and reliability. Several characteristics of the EDLS have to be traded with regard to these objectives.

5.1 Entry corridor

The entry corridor is defined by the flight path angle, FPA, and itsbandwidth, as defined in Fig 5.

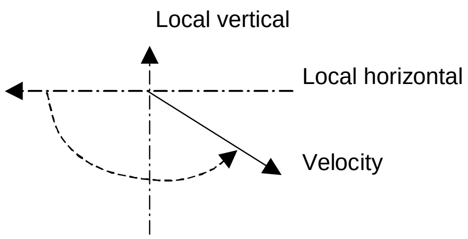

Fig 5 : Flight Path Angle

- HUYGENS

Titan's dense atmosphere requires a steep entry FPA to enable penetration up to the planet's surface. The FPA has been defined at a mean value of –64°, with +/-4° uncertainty due to CASSINI navigation and the separation device. This very steep FPA will lead to a high deceleration and heat flux level, despite the large aeroshell diameter.

- NETLANDER

The NETLANDER corridor was defined, on the steep entry by the capability to reach the altitude of 0km on MOLA reference, and on the shallow entry by engineering consideration with regard to the Thermal Protection System, TPS, capability and sizing. The corridor was then defined as [-16°;-13°], with a +/-3° uncertainty corridor.

5.2 Front shield shape

The choice of front shield shape is a compromise between:

- Drag: The trajectory behaviour is driven by the ballistic coefficient:

$$b = \frac{probe\_mass}{Frontshield\_area.x.Drag} \qquad (1)$$

  For a given performance, the higher the drag, the lower the area needed, thus the lower the mass
- Heat flux: it is expressed as the function of $1/R_N^{\ 0.5}$ with R_N describing the spherical nose radius. The lower the radius, the higher the flux, thus the higher the TPS mass.
- Stability: mainly dynamic stability at low Mach

Considering the objectives of both probes and the different environment conditions, this trade-off has led to different choices.

- HUYGENS

A cone of 60° was chosen as it provides a good drag level, and as a large amount of data is available for its aerodynamic behaviour. A large nose radius was implemented as the steep entry will lead to an important heat flux level. A 2.7 m front shield diameter provides the sufficient ballistic coefficient to reach the targeted altitude for the beginning of the scientific mission at about 170km. The conjunction of both the large diameter and the large nose radius allows a very good implementation of the Descent Module behind the front shield. This leads to a centre of gravity far forward in the probe, which hence leads to a very good static and dynamic stability of the probe. This compensates the shape's initial poor dynamic stability properties.

- NETLANDER

A cone angle of 70° was preferred as it allows both a very good drag and a CoG forward in the probe. The maximum allowable diameter of 1.2 m on the vessel was used. It allows a ballistic coefficient capable to reach the altitude requirement for landing, [5], with a parachute inflation at few kilometres above Martian surface. However, such a cone angle requires a small nose radius for stability, which induces a higher heat flux. An important point in the choice of this shape is its heritage status as it was already used for both the NASA VIKING and the Mars Pathfinder missions. The behaviour of such a front shield shape in the Mars atmosphere is thus well known.

5.3 Heat flux evaluation

The heat flux level is of primarily importance for entry probe design as it drives the TPS choice and sizing.

- HUYGENS

The convective heat flux was evaluated with Computed Fluid Dynamics, CFD. The Reynolds stays sufficiently low not to lead from laminar transition to turbulence. The maximum Argon concentration combined with minimum methane defines to maximise the heat flux. The major issue on the HUYGENS heat flux concerned the radiative heat flux. The Titan atmosphere composition combined with the high velocity entry will generate CN molecules that are known to be strong radiators [7]. The evolution of radiative heat flux is non-linear with methane mass fraction; the worst case was considered (2% to 3%). The total heat flux was then evaluated considering the worst case of upstream chemical composition of 3.5% methane, 20% Argon and 76.5% nitrogen. The maximum level is established at 1 MW/m².

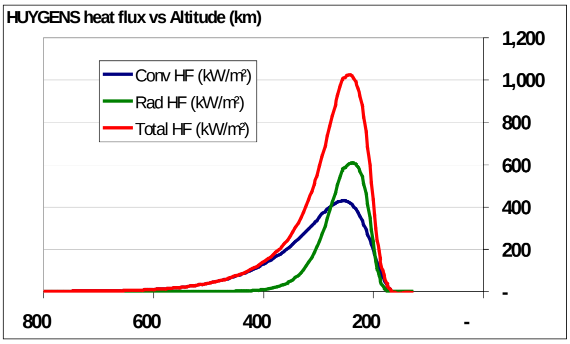

Fig 6 : HUYGENS total heat flux

- NETLANDER

NETLANDER is a small probe on which the mass constraints are emphasised. Hence, the accuracy on the heat flux evaluation has a direct impact on the probe mass budget via the TPS thickness. However, the heat flux evaluation in hypersonic flow is subject to several hypotheses, and margins must be taken into account. Laminar CFD simulations have shown the large influence of the minor species in the heat flux evaluation, [6]. The addition of C2 and CN has increased the heat flux from 5% to 15%. This chemical model is thus considered for the evaluation. In parallel, the front shield temperature is taken into account such to avoid over-sizing. Two criteria for laminar transition to turbulence have been considered. The first is based on the upstream Reynolds. The level of 5.10^5 issued from the Atmospheric Re-entry Demonstrator, ARD, was considered as opposed to the level used on VIKING, 7.10^5, and lowered the flux by 25%. The second considers the PANT criterion. This local criterion takes into account the influence of the TPS material, to indicate the occurrence of a transition on the trajectory and its location on the front shield profile. The worst case of both criterions is considered. The transition at sphere-cone junction gives a 25% increase of the laminar heat flux due to turbulence. The maximum heat flux level reached on the steep trajectory is 1.45 MW/m².

5.4 Descent phase initiation

Blunt bodies such as HUYGENS and NETLANDER are dynamically unstable in transonic flow. It is then necessary to deploy a parachute that will ensure the probe stability during this critical phase. The sizing criterion for the initiation of this phase is the Mach. The easiest and more reliable measurement in entry trajectories is the acceleration. Almost every method for initiation of descent phase is based on accelerometric measurements correlated with Mach prediction.

- HUYGENS

Despite the existence of the Lellouch-Hunten atmosphere model, uncertainty remains about the validity of this model. Hence, it was preferred to base the timeline on true acceleration measurements rather then on engineering predictions. The entire timeline is then sequenced by acceleration thresholds. The sequence is reset at the entry atmosphere detection, and then the pyrotechnical devices are armed at 9.5m/s². The threshold of the acceleration for the descent initiation has been set at 10 m/s² as it allows a good accuracy in this range of acceleration. Then, a timer triggers the sequence..

This full mission phase is fault tolerant. Full redundancy is implemented on acceleration measurements (3 accelerometers, plus G-switches), on actions and events (pyros), and on the avionics with 2 chains in parallel that are partially cross-trapped. The design has been verified for full operation with a single failure, and exhibits a good robustness level to some multiple failures. In addition, a time-out on the entry detections has been implemented as a last chance device in case of large multiple failures.

- NETLANDER

The system has to cope with a large FPA corridor and wide atmosphere conditions. It has not been possible to define a unique acceleration threshold that copes with all the possible cases, as on HUYGENS. It was then chosen to use a statistical algorithm based on trajectory predictions. The algorithm chosen is based on multiple threshold detections and an additional timer. The Mach1.5 is targeted for the descent phase initiation.

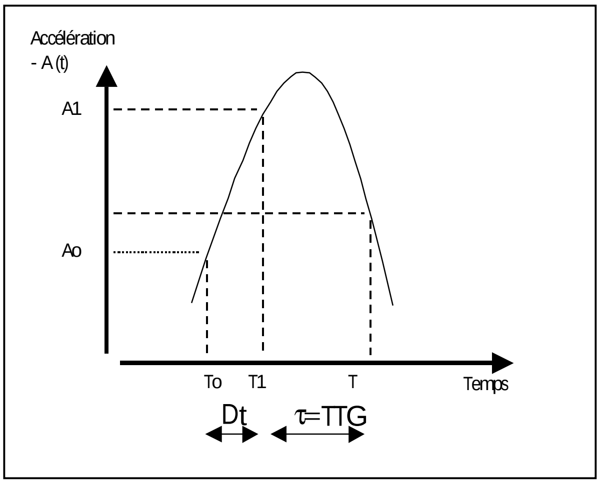

Fig 7 : NETLANDER Algorithm principle [5]

The entry principle is the following (Fig 7):

- An acceleration threshold, A0 is crossed, at which the time T0 is recorded,

- At T1 = T0+Δt, the acceleration A1 is measured
- Then, the time from T1 to reach Mach=1.5 is calculated, TTG (Time To Go).

The algorithm is based on the fact that a strong correlation exists between A1 and TTG. Before the mission, a Monte-Carlo analysis is performed including all uncertainties (FPA, velocity and atmosphere). Then a correlation is established between A1 and TTG. NASA's Mars Pathfinder has used such an algorithm with a linear regression. Considering the wide range of atmosphere conditions issued from EMCD, a third order regression was preferred for NETLANDER (Fig 8).

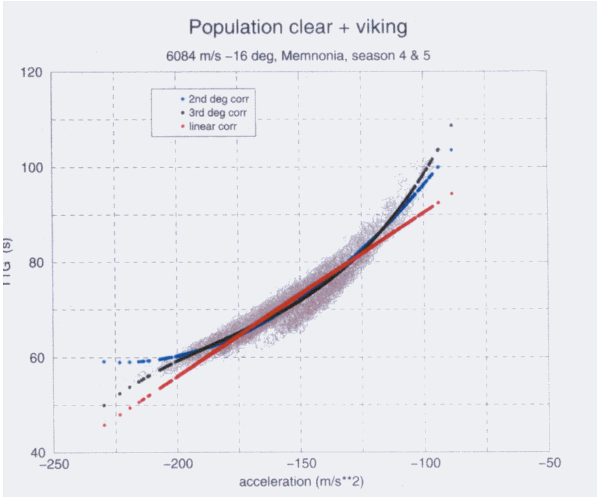

Fig 8 : NETLANDER algorithm regression (example) [5]

In consequence, the coefficients of the regression are implemented in the NETLANDER onboard computer. They can be tuned during the cruise to Mars, depending on the chosen landing site for each probe. After the first parachute deployment, the sequence is triggered via a timer.

5.5 Descent system

The descent system has two main functions:

- Ensure the probe stability during the transonic phase
- Reduce the velocity to a level in accordance with the preferred descent duration for HUYGENS and with the landing system capability for NETLANDER

- HUYGENS

A first parachute, the pilot chute is deployed right at the descent phase initiation, Mach 1.5. It is a 2.6m double gap disk gap band. With its inflation, it releases the back cover and deploys the 8.3m diameter main chute that maintains the probe stability during the transonic. However, this parachute is too large to comply with the full descent duration. Therefore, 15 minutes after the main chute deployment, a small stabiliser chute of 3m diameter is deployed to cope with the 2.5 hours descent requirement (Fig. 9).

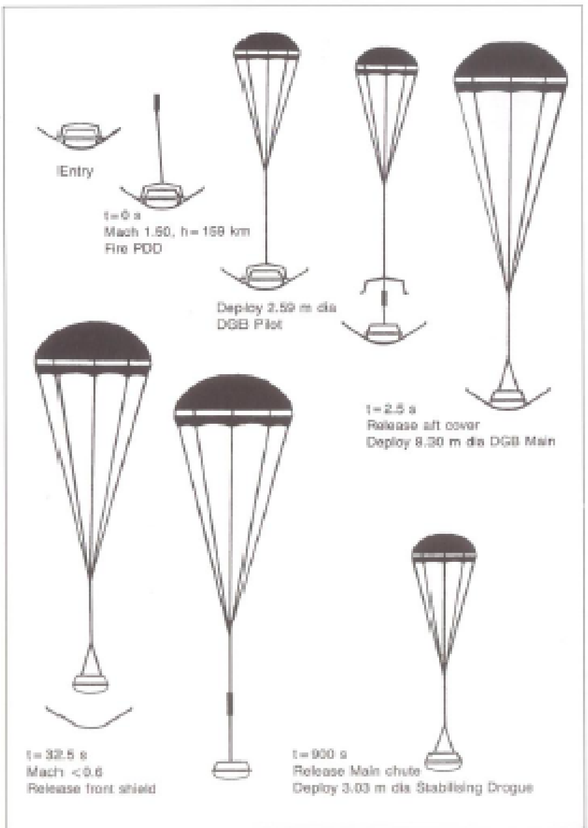

Fig 9: HUYGENS Descent sequence

The spin velocity requirement by DISR instruments is ensured via 36 dedicated spin vanes implemented on the descent module fore dome (Fig 10). The incidence of these spin vanes induces a positive motor torque which increases the spin rate, [7]. But with the spin rate increase, the local incidence become negative, resulting a negative torque. Then an equilibrium rate is established. A swivel is added in the parachute main bridle to limit the parachute spin.

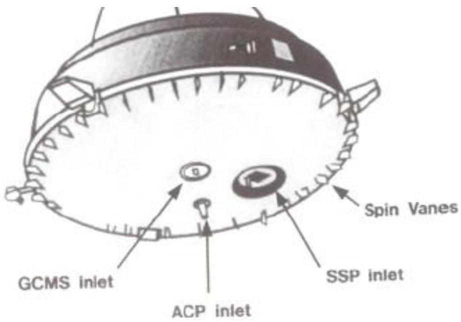

Fig 10: HUYGENS spin vanes implementation

- NETLANDER

Two parachutes are used for the NETLANDER descent to the Mars surface. First a drogue chute is designed for the transonic range [8]. A circular shape is chosen for efficient aerobraking and stability (Fig. 11). Then 7s after the drogue chute deployment, it is released and deploys the main chute. A cruciform shape was preferred for stabilisation down to landing velocity and mass optimisation, [8] (Fig. 12).

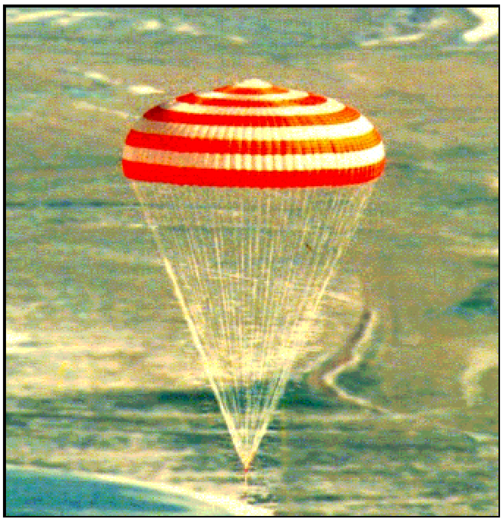

Fig 11: NETLANDER drogue chute (example)

Fig 12: NETLANDER cross shape parachute as deployed

5.6 Landing system

- HUYGENS

No landing system was defined for HUYGENS as this was not a mission requirement. However, the stabiliser parachute reduces the velocity to a landing velocity of 5m/s, which is a relative low level. The survivability of the probe due to the surface impact will depend on the ground material. A design goal has been to have about 3-minutes survivability on the Titan surface.

- NETLANDER

The NETLANDER mission starts after the landing, so this phase is an important part of the mission. The landing subsystem is based on airbags that will protect the payload from the landing impact,[8]. The landing velocity has been optimised with regard to the mass of the descent system and airbag, as shown in Fig 13. The airbag is a MARS 96 heritage (Fig. 14).

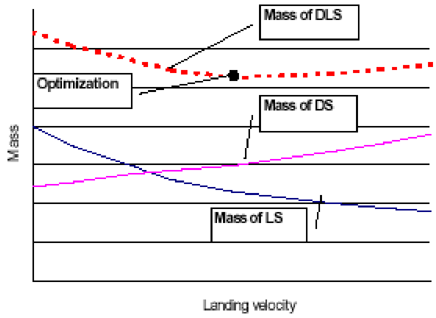

Fig 13: Trends of mass optimisation

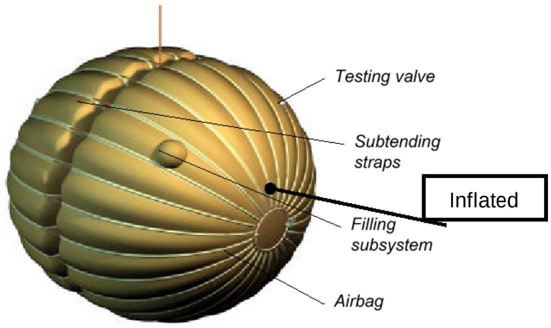

Fig 14: Inflated airbag

In order to avoid any re-contact between the air bags and the parachute at first bouncing, going up to about 80m high, a 150m fall line is deployed between both elements. This fall line is cut directly at the first touchdown. After stabilisation on ground, the airbags are separated to deliver the surface station on Mars.

6. Probe design

- HUYGENS

The HUYGENS probe (Fig. 15) is composed of an aeroshell, which protects the Descent module from the entry aero-thermal environment. A mortar placed in the back cover is destined to separate the pilot chute from the probe to allow its inflation. Both main chute and stabiliser chute are attached on the Descent Module.

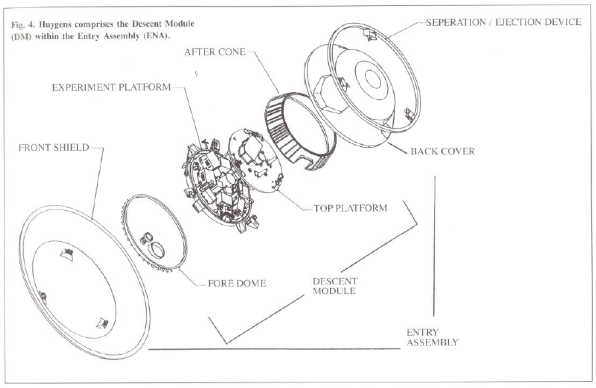

Fig 15: HUYGENS probe design

- NETLANDER

The NETLANDER design presented in [9] is recalled in Fig 16 below.

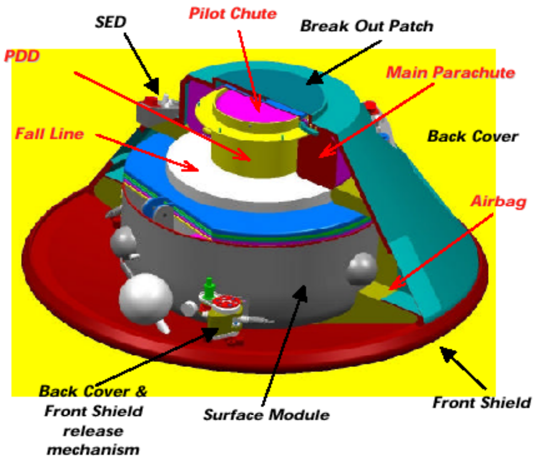

Fig 16: NETLANDER probe design

7. Mission timeline

Based on the trade-offs and the design presented above, the mission timeline for both missions are presented in Fig 17 and 18 below, for the HUYGENS and NETLANDER missions respectively.

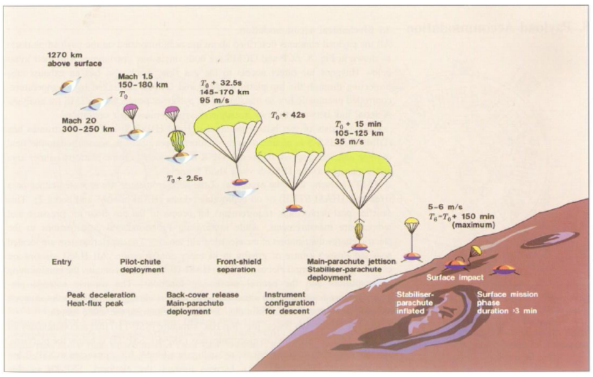

Fig 17: HUYGENS mission timeline [1]

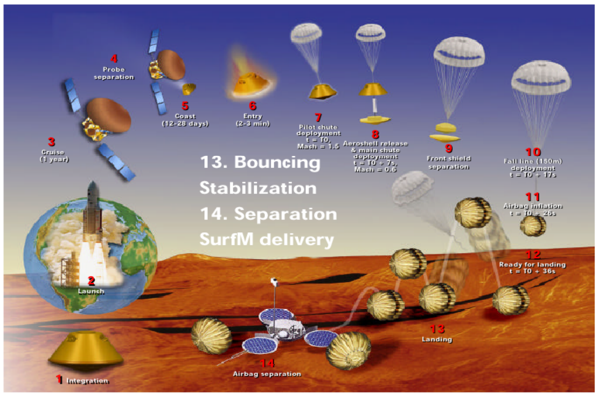

Fig 18: NETLANDER mission timeline

8. Mission status

HUYGENS and CASSINI are now at almost 6 months from the Saturn system. The HUYGENS mission will be performed in January 2005. The Industrial team headed by ALCATEL SPACE is now verifying the design compatibility with various upgraded atmosphere models.

The NETLANDER/EDLS project led by ALCATEL SPACE has successfully closed its system and subsystem Preliminary Design Reviews. The project has been stopped before entering in phase C/D.

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